

SOME PROPERTIES OF RARITY SCORES USED IN SITE QUALITY ASSESSMENT

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Abstract. Species lists for sites are often compared for rarities using an index of the average or mean national range size of the species ('species quality score' or SQS). This paper describes some properties of SQS that need to be kept in mind when interpreting the results, illustrated using atlas data for bumble bees on a 10 × 10 km grid. Results show that SQSs may be correlated (1) with recorded species richness; and (2) with recording effort. With these data, national SQSs are capable of identifying concentrations of species with narrow national distributions even within species-poor areas of northern Britain, so that a separate regional treatment is not always necessary. However, the most important observation is that, despite these correlations, the most extreme high and low SQS values can only occur when recorded species richness is low, which, when due to low recording effort, could be very misleading. Similar measures of range-size rarity from the conservation literature are discussed, as well as other approaches for looking at how available data may be used to find combinations of sites (some of them species-poor but with rare species) that represent a greater diversity of wildlife.

INTRODUCTION

Rare species are often given special value, particularly for conservation (e.g. Ratcliffe, 1977; Usher, 1986; Callicott *et al.*, 1999). Once species lists have been compiled for a number of sites, people like to compare them to see which sites have more of the rarer species (e.g. Lott *et al.*, 1999), even when conservation areas are chosen using other criteria. Rarity of species is often assessed in terms of the sizes of their distribution ranges (Rabinowitz, 1981; Gaston, 1994), at least when information on population sizes is unavailable. To compare sites, simple sums of species-rarity scores have been used, as well as more complex indices (see bibliography by Eyre, 1996b).

One apparently straightforward index of rarity for a site is the average or mean range size among the recorded species. This 'species quality factor', 'species quality score', or 'Species Quality Index' was proposed originally for assessing sites by regional rarity of species (Foster, 1987; Eyre & Rushton, 1989; Foster *et al.*, 1990; Crossley, 1996; Eyre, 1996a; Eyre *et al.*, 1996; Foster, 1996; Luff, 1996). Later, it was extended to represent national rarity within Britain, as a 'Species Quality Index', 'species quality score', or 'Species Quality Factor' (Ball, 1992; Archer, 1995, 1996a, b, c, d, 1997a, b, c, 1998a, b, 1999a, b, c; Eyre *et al.*, 1996). This index (henceforth 'SQS') is based on the average or mean of national rarity 'status scores' among the species recorded at a site. SQSs above a particular value are then considered to indicate places with high conservation value for the group concerned.

The aim of this paper is to describe some properties of SQS. The analysis uses atlas data for bumble bees recorded on a grid of 10 × 10 km cells, rather than the smaller sites that are of more interest to many field workers. This choice should not be taken to imply either that this is necessarily the most appropriate scale for analysis, or that bumble bees are a particularly appropriate group for area assessment. Rather, these data are used to illustrate what are expected to be general properties of SQS (and of

similar indices using mean-rarity scores) that arise from the form of the index, and which need to be kept in mind when interpreting the scores.

Two important claims made for SQS are explored here. These are, first, that variation among sites in SQSs shows a positive relationship with the numbers of species (Archer, 1995); and second, that the SQS corrects for differences in recording effort among sites (e.g. Foster, 1987; Ball, 1992; Archer, 1996a). Similar measures of range-size rarity from the conservation literature are discussed, as well as other approaches for looking at how available data may be used to find sites that, in combination, could represent a greater diversity of wildlife.

METHODS

The idea behind the SQS is to weight species according to the size of their distribution ranges within Britain, giving the highest weights to the most restricted species. Archer (1995) described one national scoring scheme. This was based initially on Red Data Book categories for species (as revised by Falk, 1991), although the definition of the categories or classes of species has since been modified, so that they have become grouped primarily by numbers of 10×10 km grid cells with post-1970 records (Table 1). Species in each range-size class are given a particular score, and these scores are added up for a site from all of the species in the site list. The total species score is then divided by the number of species recorded to give an SQS for the site. In some studies, scores above 2.0 have been suggested to indicate 'good quality' sites (Foster & Eyre, 1992; Archer, 1996a).

An assessment of some of the properties of the SQS can be made using published data for bumble bees, a small but relatively well known group of insects. Groups with a few species are not typical of SQS applications, but can still be useful for illustrating its mathematical properties. Twenty-two species of bumble bees have

TABLE 1. Species status scores within Britain for the 22 species of bumble bees (*B. magnus* is treated as part of *B. lucorum* in the broad sense) interpreted from Archer (1998b) and the status categories from Archer 1997b).

Status	Criteria (British range extent)	Status score	Bumble bees (<i>Bombus</i>)
universal	>70 10×10 km grid cells + ITE Land Classification groups 1-8	1	<i>barbutellus</i> , <i>bohemicus</i> , <i>campestris</i> , <i>hortorum</i> , <i>lapidarius</i> , <i>lucorum</i> s.l., <i>pascuorum</i> , <i>pratensis</i> , <i>sylvestris</i> , <i>terrestris</i>
widespread	>70 10×10 km grid cells +ITE Land Classification groups 1-4 (c. 75% Britain)	2	<i>jonellus</i> , <i>monticola</i> , <i>muscorum</i> , <i>vestalis</i>
restricted	>70 10×10 km grid cells +ITE Land Classification groups 1-2 (c. 50% Britain)	4	<i>humilis</i> , <i>ruderalsis</i>
scarce	31-70 10×10 km grid cells	8	<i>distinguendus</i> , <i>ruderalsis</i> , <i>rupestris</i> , <i>sorocensis</i> , <i>sylvaticus</i>
rare	16-30 10×10 km grid cells	16	(none)
very rare	1-15 10×10 km grid cells	32	<i>subterraneus</i>

been recorded post-1960 among 2199 of the 10 × 10 km grid cells in Britain (excluding Ireland, where recording effort was generally lower) by the Bumblebee Distribution Maps Scheme (Alford, 1980). A study across the whole of Britain is used to find out to what extent the SQS can identify faunas rich in rare, regionally specialist species, even when the analysis is not subdivided by latitude, climatic regions, or major land-classification groups. The bumble bee atlas maps do not show post-1970 records separately, so post-1960 records have had to be used (for some species at least, there is doubt concerning validity of some of the records: Edwards & Roberts, 1998; although this should not affect the conclusions here). Archer (1998b) has already published species status scores for bumble bees in Britain, as shown in Table 1. Treating the 10 × 10 km grid cells as 'sites' for the purposes of this exploratory analysis, the SQSs for bumble bees from the atlas data can then be mapped (Williams, 1996). For bumble bees, this change of scale from smaller sites to 10 × 10 km grid cells should not be as severe a misrepresentation of patterns of co-occurrence among species at local sites as it might be for some other groups, because these bees may forage several kilometres from their nests.

Unfortunately the 'true' species richness of a site, and the amount of effort put into recording from it, are usually only poorly known (e.g. Colwell & Coddington, 1994; Dennis *et al.*, 1999). As with most atlases, the bumble bee atlas has no map of variation in the intensity of recording effort, only a map showing the cells from which at least one record was received. One possibility is to use the number of recorded 'mainland ubiquitous species' (Williams, 1982: *Bombus hortorum*, *lapidarius*, *lucorum*, *pascuorum*, *pratorum*, *terrestris*) as a rough measure of recording effort, because these species appear to be nearly ubiquitous where adequate sampling effort has been expended, at least for much of central and southern Britain (Williams, 1988). Scotland and the Isle of Man are excluded for this part of the analysis concerning recording effort, because some of the mainland ubiquitous species (particularly *B. lapidarius*, *terrestris*) are genuinely less widespread there (pers. obs.).

RESULTS AND DISCUSSION

Fig. 1 maps SQSs for bumble bees from the atlas data. The map shows weak aggregations of high scores associated with the more restricted species, which were recorded primarily in the north west and south east of Britain. Therefore, at least with these data, national SQSs are capable of identifying concentrations of records for species with narrow national distributions even within northern Britain. Therefore, the choice of whether to use a national or a regional basis for the SQS should depend on whether the goal of the study is to assess sites within a national or a regional context. A similar geographical pattern of range-size rarity is known from some other groups of organisms, such as birds (Williams, Gibbons *et al.*, 1996: fig. 1).

(1) SQS and species richness

SQSs are correlated with recorded richness in all species for the bumble bee atlas data (Spearman rank correlation $r_s = 0.44$, $p < 0.001$, if data points are assumed to be independent). Nonetheless, the highest SQSs come from cells with fewest recorded species (Fig. 2a). This is a result of dividing the cumulative species scores by the numbers of species, because the highest site scores can only be obtained where all species share the highest status scores (which is almost inevitably where these species are few in number). As the number of species recorded approaches the total of 22, so

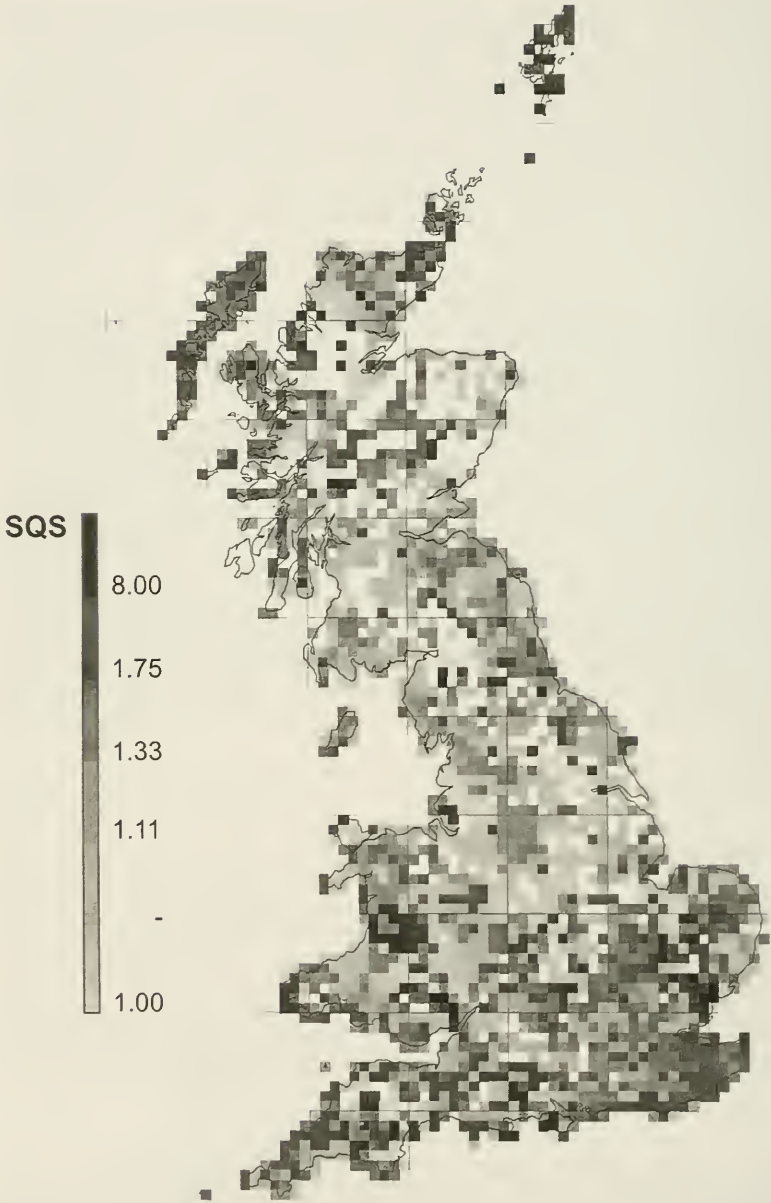


Fig. 1. SQSs for 10×10 km grid cells from the species-status scores in Table 1 and records from the bumble bee atlas (Alford, 1980). Each grey scale class represents approximately one fifth of the map (except where constrained by large numbers of ties), with black for the maximum score (8) and pale grey for minimum scores (1).

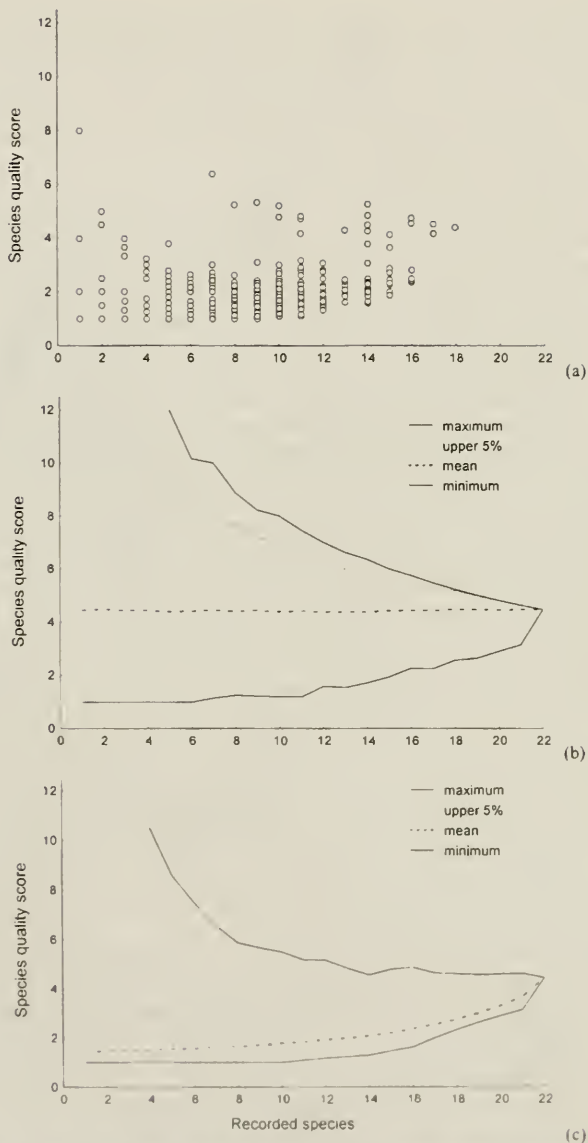


Fig. 2. (a) SQSs for 10×10 km grid cells (see Fig. 1) from the species-status scores in Table 1, plotted against number of species recorded in the bumble bee atlas (Allford, 1980). (b) Simulated SQSs for 10×10 km grid cells by drawing species randomly (1000 times without replacement) from the species-status scores in Table 1, for each number of species. The probabilities of drawing each species are equal. (c) As (b), but the probability of drawing a species is dependent on the number of grid cells from which it is recorded in the bumble bee atlas. Axes are drawn to the same scale to aid comparison, although the maximum possible score for one recorded species is 32.

site scores must converge on the overall mean score among species (in bumble bees from Table 1, this is 4.45), creating the 'funnel' effect shown towards the right of Fig. 2a. The problem with this is that a species-rich site could end up with a lower SQS than another site with the same rare species, but with a subset of the same widespread species (e.g. a site with all of the bumble bee species would score 4.45, whereas a site with the same fauna but lacking *B. lucorum*, *pratorum*, *bohemicus* and *sylvestris* would score a higher 5.22).

The funnel effect can be demonstrated by simulating randomly drawn bumble bee faunas and calculating their SQSs, as shown in Fig. 2b. This procedure naïvely assumes that each species is equally likely to be chosen. Comparing Figs 2a and 2b, it appears that the SQSs observed from the bumble bee atlas data tend to lie towards the lower end of the range of scores expected by chance, at least for smaller numbers of recorded species. This bias arises because, in reality, smaller faunas are often made up disproportionately from the more widespread species, which contribute lower scores to the SQSs. Therefore Fig. 2c repeats the simulation of drawing species at random, but this time takes range size into account, by assuming that the chance of drawing any one species is related to the number of cells from which it is recorded nationally in the bumble bee atlas. The positive slope of the expected mean SQS line in Fig. 2c ($r_s = 0.22$, $p < 0.001$) shows that this range-size effect is likely to be responsible for the positive correlation between SQSs and species richness for the bumble bee atlas data in Fig. 2a. In addition, if the widespread species were also the more abundant species locally, then they would be even more likely to be recorded from the richer cells when sample sizes were small (see (2) below). Thus, Fig. 2 illustrates a serious limitation of using mean (or median) scores among species: that the highest site scores can only be obtained for sites where few species have been recorded. The same is true of the lowest site scores, although they are less constrained by recorded richness because there are more of the 'universal' species (Table 1). Low recorded richness may arise because sites are simply under-recorded (very likely in this case: see below), although SQS could also give the highest scores to sites that are genuinely most species-poor. The funnel effect should be less of a problem when dealing with many larger groups, such as all solitary bees and wasps (as in the case of Archer's studies), because the maximum number of species occurring at any one site or 10×10 km grid cell is likely to be a smaller proportion of the total number of species (e.g. less than 50% when recording all British aculeate species. (S. Roberts pers. comm.), compared with up to 86% of bumble bee species (pers. obs.).

Fortunately, the simulation approach offers a way to judge whether a cell has a higher or lower SQS than would be expected by chance, given the number of species recorded. Any SQSs in Fig. 2a that fall above the upper 5% dotted line in Fig. 2c would be significantly higher than expected. There are 87 cells with these scores (Fig. 3), which is actually 4% of the total cells with records, so the simulation in Fig. 2c appears to fit the data reasonably well. Therefore, as a general guide, because the upper 5% line in Fig. 2c lies at SQSs of approximately 4.0 for these data, cells scoring more than 4.0 might be considered of special interest. This is considerably higher than the threshold of 2.0 recommended (for different data) by Foster & Eyre (1992) and by Archer (1996a). Two qualifications are important. First, this value is expected to differ among data sets because it depends on the range sizes within Britain of the particular set of species. Second and more important, rather than reflecting patterns of biological interest, even significantly higher values could simply be the result of under-recording, as discussed below, or of selective recording. Comparing the geographical distribution of extreme probability

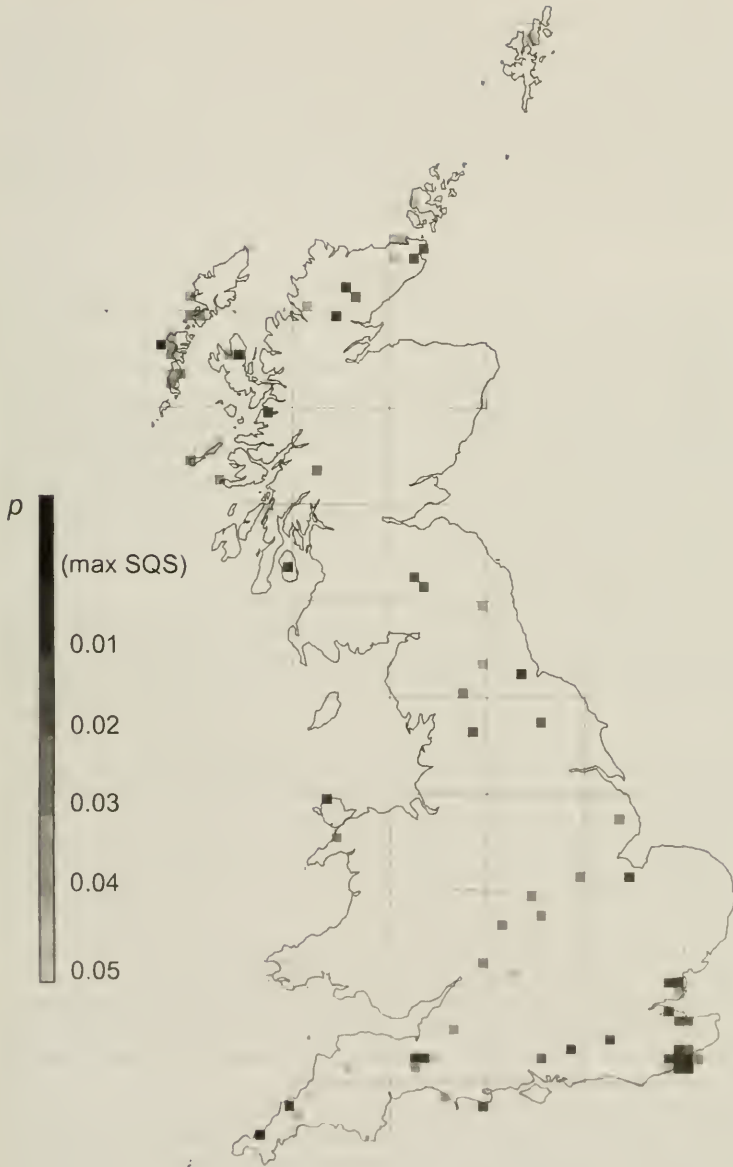


Fig. 3. 10 × 10 km grid cells with significantly higher SQSs (Fig. 2a) from the bumble bee atlas data (Alford, 1980) than would be expected by chance for their levels of species richness (i.e. cells above the fine dotted line in Fig. 2c). The grid-cell values show the estimated probabilities of obtaining the SQSs from Fig. 1 that fall within the upper 5% tail of the simulated distribution in Fig. 2c for each level of species richness ('max SQS' is the maximum score obtained from the simulation in each case).

estimates for SQSs in Fig. 3 with the original bumble bee SQSs in Fig. 1. Fig. 3 gives less emphasis to some apparently high-scoring regions, particularly in Shetland, the Grampians, and Wales. If some of the rarer species of northern and upland areas are actually valued by people more highly than Fig. 3 would imply, then (rather than dividing the analysis by region within Britain) an appropriate recognition of this higher value would be to upgrade the status scores for these species in Table 1 and re-calculate the SQSs. On the other hand, Fig. 3 does draw particular attention to the area around Dungeness, which is well known for its rich bumble bee fauna with many rarities (e.g. Williams, 1989).

(2) SQS and recording effort

SQSs are correlated with recording effort as measured by recorded richness in mainland ubiquitous species from the bumble bee atlas data (Fig. 4: $r_s = 0.37$, $p < 0.001$). Of course, a question mark has to remain over whether richness in mainland ubiquitous species provides a good surrogate for measuring recording effort, at least until the relationship can be tested over a broad region of the country. Nonetheless, a correlation between SQSs and recording effort would be expected because the rarer bumble bee species (which contribute most to the SQSs) also tend to be the less abundant species locally (at least when measured across several sites where they are present: Hanski, 1982; Williams, 1988), and are therefore most likely to be recorded from the more intensively recorded cells (along with more species of mainland ubiquitous bumble bees).

Despite the correlation between SQSs and recording effort, the highest SQSs come from cells with no records of the mainland ubiquitous species (Fig. 4). One explanation for such high scores for these cells may be the chance effect of recording just a few rare species from within larger faunas (compare Fig. 2), if these cells had indeed been particularly poorly recorded (it has been known for people to find only the very rare *B. subterraneus* in samples of just one or two bees). Consequently, even some of the high-scoring cells from Fig. 2a that are significantly higher than expected by chance in Fig. 2c may only appear to be of high value because of under-recording and the sensitivity of the SQS at low recorded richness.

If suitable data on local abundances of each species were available, it would be possible to take sub-samples of bees from these data at random (a 'rarefaction' method) in order to assess the effect of sample size (as a measure of recording effort) on the SQSs for sites. Similar methods could in principle be used to compare SQSs among sites, if data for recording effort were available, using a modification of the method described by Prendergast *et al.* (1993b). Unfortunately, however, the popular methods that use data from small samples to extrapolate an expected species richness for a site (e.g. Colwell & Coddington, 1994) are of little use for calculating SQSs, because the identities and range sizes of the expected but unrecorded species remain unknown.

The sites surveyed by Archer (1995, 1996a, b, 1999b, c) were much more intensively and consistently recorded than were many of the cells recorded for the bumble bee atlas. Some scoring studies have tried to ensure consistency in recording effort by incorporating thresholds that must be reached before scores may be considered reliable (e.g. Hammond & Harding, 1991). However, using thresholds based on the species data relies on assumptions of what the data and thresholds are expected to look like. Whenever the opportunity arises, it would be better to avoid the need for these assumptions by trying to ensure from the outset that samples are as large and as comparable in terms of recording effort as possible (e.g. Rich, 1997).

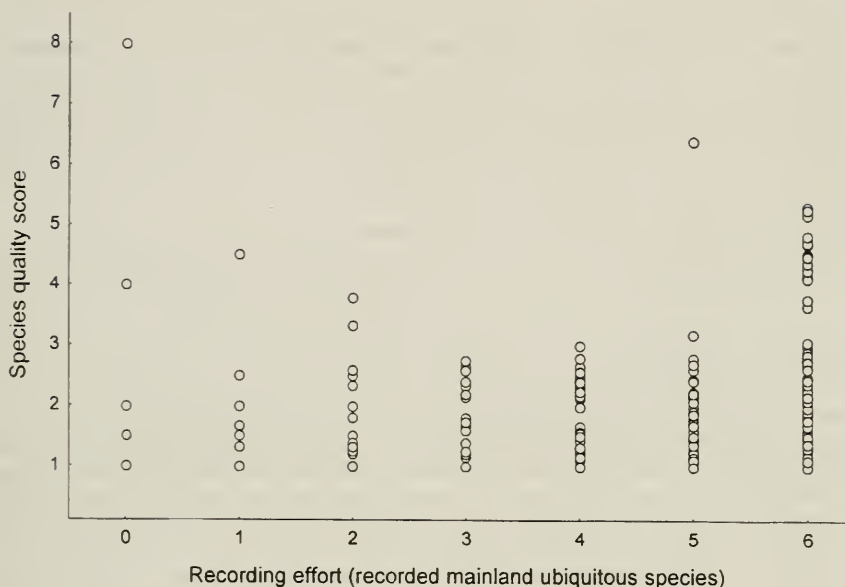


Fig. 4. SQSs for 10×10 km grid cells (see Fig. 1) from the species-status scores in Table 1, plotted against recording effort, measured using the number of mainland ubiquitous species recorded in the bumble bee atlas (Alford, 1980), excluding records for Scotland and the Isle of Man.

For this purpose, standards for recording effort ought to be measured in terms of something like area searched or time expended (bias is introduced if thresholds are applied to characteristics of the sample used in the index, such as species richness). Indices should then be able to apply rarity criteria more consistently, even at a national scale, reducing the need to restrict comparisons of SQS to particular habitats or regions.

RELATED MEASURES OF RANGE-SIZE RARITY

Two other closely related measures of where rarities occur have been in use in conservation studies for some time. These measures do require a more precise knowledge of the range sizes of the species (e.g. from atlas data), but they also avoid the need to define an arbitrary number of status classes. In addition, all of these measures could use measures of European or global range size, in place of range size within Britain, if this were considered more appropriate to the aims of a study, and if the data were available.

First, rather than putting species into groups by their range sizes, 'range-size rarity' measures are simple indices calculated directly from estimates of range sizes. There is no clearly best or 'natural' index for this, although the most popular formula has been the sum of the inverse of the range sizes (Table 2, middle row). Thus for grid-based data, if a species is recorded from 1 cell it scores 1, from 10 cells it scores 0.1, from 100 cells it scores 0.01, and so on, and the scores are added up for the

Table 2. Examples of indices of range-size rarity using continuous functions of range size. In effect, the relative weighting given to the most restricted species increases (and sensitivity to richness decreases) in the indices towards the bottom of the table. Range size may be measured, for example, as the number of occupied cells (c_i) for species (i) in a grid. C is the total number of cells in the grid and S is the total number of species. The score for a grid cell is the sum of the scores from all of the species recorded as present within it. Symbols have been changed from original references in order to standardise formulae.

Formula	Examples
$\sum_{\{i:c_i \neq 0, 1 \leq i \leq S\}} (C - c_i)$	Daniels <i>et al.</i> , 1991
$\sum_{\{i:c_i \neq 0, 1 \leq i \leq S\}} (1/c_i)$	Jefferson, 1984; Usher, 1986; Avery & Leslie, 1990; Howard, 1991; Turpie, 1995; Williams <i>et al.</i> , 1996
$\sum_{\{i:c_i \neq 0, 1 \leq i \leq S\}} (1/c_i^2)$	Williams, 1996

species recorded in each cell. The effect is to give greater weight to the most restricted species, while the widespread species have little effect on the scores. The scores for cells may then be divided by the numbers of species recorded within each cell in order to provide a measure sensitive to the proportion of relatively restricted species (e.g. Williams, Gibbons *et al.*, 1996: fig. 1d; Williams, Prance *et al.*, 1996: fig. 4). Geometric weighting of range size by the mean inverse formula is very similar to the weighting in SQSs, as shown by a high correlation for the bumble bee atlas data ($r_s = 0.86$, $p < 0.001$).

Second, a much simpler measure that has been used to show where rarities occur is the median range size among the species recorded for each cell (Smith *et al.*, 1994). It has the advantage that properties of the median are well understood. The disadvantages are that its value decreases as the proportion of restricted species increases and, of more importance, that it is more strongly influenced by the more widespread species. Consequently it is not as closely correlated as inverse range-size rarity with SQSs for the bumble bee atlas data ($r_s = -0.68$, $p < 0.001$).

Both of these measures are easily calculated for large numbers of atlas data at any spatial scale using widely available personal computers. However, because they both have fundamentally similar formulations to the SQS, they also suffer from similar limitations, and particularly from the funnel effect of converging scores at high species richness (discussed by Williams, Prance *et al.*, 1996).

Slightly different are measures of rarity that include scores for species only if they are more restricted than some threshold (Gaston, 1994). Excluding widespread species from scoring has been used in studies at local (e.g. Hammond & Harding, 1991), continent-wide (Terborgh & Winter, 1983), and world-wide (ICBP, 1992) scales. Just as there is no 'natural' formula for the measures of range-size rarity described above, so the choice of range-size threshold also has to be essentially arbitrary. Thresholds have been criticised because they will always miss species with marginally larger ranges that are important to some people (Crowe & Siegfried, 1993).

RECOGNISING IMPORTANT SITES

The conservation value of sites depends on many factors, some of them purely social, and some of them depending on socially-valued biological attributes (e.g. Goldsmith, 1991). Quantitative methods for scoring the biological value of sites (and

often by implication, selecting 'hotspots' of various kinds, see Prendergast *et al.*, 1993a, b; Palmer, 1999) are a practical way of helping to make the basis of expert opinion more explicit and accountable when faced with difficult and contentious decisions. If people would like to conserve species, then (ignoring questions of whether these species are more or less widespread outside Britain) a species' range size within Britain gives one crude measure of the relative number of opportunities for representing it here for the future.

Ultimately, if the aim is to conserve as many species of bees, wasps, ants (or any other organisms) as possible, despite limited opportunities, then we will have to move from simple hotspots to other approaches that consider how combinations of sites (and different forms of management) can represent this diversity of species (Pressey & Nicholls, 1989). The solution to the selection part of the problem is to use the simple idea of complementarity, which allows the greatest combined numbers of different species to be represented. This approach can avoid representing many common species more than may be necessary at the cost of missing many rarer and more specialised species, many of which may occur only within species-poor sites. For an example of the principle using British data, see Williams, Gibbons *et al.* (1996), although ideally the areas used should be appropriate land-management units, not 10 × 10 km grid cells. Table 3 shows how these hotspots of complementary richness can increase the representation of the rarest species in particular (if preferred, this method could also be used to seek the maximum possible representation for these species to add to existing conservation areas). As with any approach, it is vital that the many other important constraints be taken into account, including local viability, threat and cost, from whatever information is available (reviewed by Williams, 1998). With complementarity, the emphasis is not primarily on the diversity or rarity of species at a site, but on which species a site can contribute (as good viable populations) towards a broader plan for representing British wildlife for the future (the choice and scale of appropriate management will depend on many biological and social factors). This approach is not fundamentally opposed to other methods, neither is it any more prescriptive: it merely makes it possible to identify

Table 3. Number of representations for bumble bee species from atlas data (Alford, 1980) in 10 × 10 km grid cells selected by three methods. The cells in the fourth column are the 87 cells in Fig. 3 with significantly higher SQSs than expected by chance (Fig. 2c). Taking this arbitrary number as a basis for a comparison, the hotspots of richness in the third column are the 87 cells with the highest numbers of species records in the atlas data. The hotspots of complementary richness in the last column are obtained by searching for a set of 87 cells with the maximum coverage of every species (87 cells is just below the 90 cells that would be required to represent every species at least 24 times, or for the more restricted species, such as *B. subterraneus*, to include all 22 cells with atlas records).

Bumble bees (<i>Bombus</i>) by status class (see Table 1)	Records in 2199 British grid cells (totals)	Records in 87 hotspots of richness	Records in 87 cells with unexpectedly high SQSs	Records in 87 hotspots of complementary richness
universal	9196	770	289	525
widespread	1247	163	77	134
restricted	552	118	49	67
scarce	395	117	101	121
very rare	22	14	21	22

and fill 'gaps' in existing conservation coverage more easily, ideally by putting good autecological and synecological studies of species within a larger framework.

SQS and similar indices based on means are relatively easy to calculate. However, when using them, biologists need to be aware that, with under-recording, they may generate extreme and misleading values, and that scores tend to converge on a group's mean score when most species in the group co-occur. These methods (if applied to comparable large samples and interpreted with care) could provide a rough guide to the contribution that sites can make to representing the diversity of wildlife, but only if (as may often be the case) rare species are likely to differ among sites. More reliably, complementarity methods, which take direct account of species differences among sites, will usually identify combinations of sites that represent more species in total.

ACKNOWLEDGEMENTS

This study is only possible thanks to the many volunteer field workers who contributed the atlas records, and to the International Bee Research Association and the Biological Records Centre for compiling the atlas maps. My thanks to M. Archer, M. Edwards, M. Eyre, P. Hammond, L. Manne, C. Moncrieff, R. Vane-Wright and a referee for comments and discussion.

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